REPORT No. 31.

DEVELOPMENT OF AIR SPEED NOZZLES.

By A. F. ZAHM.

CONTENTS.

PREFACE.

The work here outlined was done to develop a suitable speed nozzle for the first few thousand airplanes made by the United States during the recent war in Europe, and to furnish a basis for more mature instruments in the future. Forty thousand of these nozzles were ordered by the Government, and 12,000 were made before the cessation of hostilities.

The preliminary experiments were made by Messrs. L. Ofenstein and William H. Gornal; the later ones by Messrs. L. H. Crook, G. J. Chaillet, and R. H. Smith; the illustrations were arranged by Messrs. L. Thoms and S. S. Rathbun; all aeronautical assistants in the Construction Department, Washington Navy Yard.

The manufacture and inspection of the first nozzles for the Government were supervised, respectively, by Naval Constructor William McEntee, U. S. N., for the Navy, and Maj. C. E. Mendenhall, R. C. A. S., for the Army. Their tests supplied some of the tables here given for the performance, in laboratory and field, of the final standard nozzles joined to adequate pressure gauges.

Requirements.—To provide a suitable pressure collector for aircraft speed meters an effort was made, early in 1917, to develop a speed nozzle which should be waterproof, powerful, unaffected by slight pitch and yaw, rugged and easy to manufacture, and uniform in structure and reading, so as not to require individual calibration. Existing nozzles had not all these properties. Some exerted feeble pressure, others were slow and costly to make, and none were waterproof. For example the nozzles shown in Figures 1 and 2, though valuable under favorable conditions, are neither waterproof nor powerful in action.

PITOT-VENTURI NOZZLE No. 1.

General features.—Figures 3 and 4 give the outward appearance and structural details of nozzle No. 1, made in the spring of 1917. A single casting, fixed by its flange to a strut, comprises two laterally-downward sloping ducts, one terminating in a small pitot elbow, the other ending transversely in the throat of a double-cone venturi tube. In normal working, the air blows straight into the pitot mouth, generating therein full impact pressure; also it

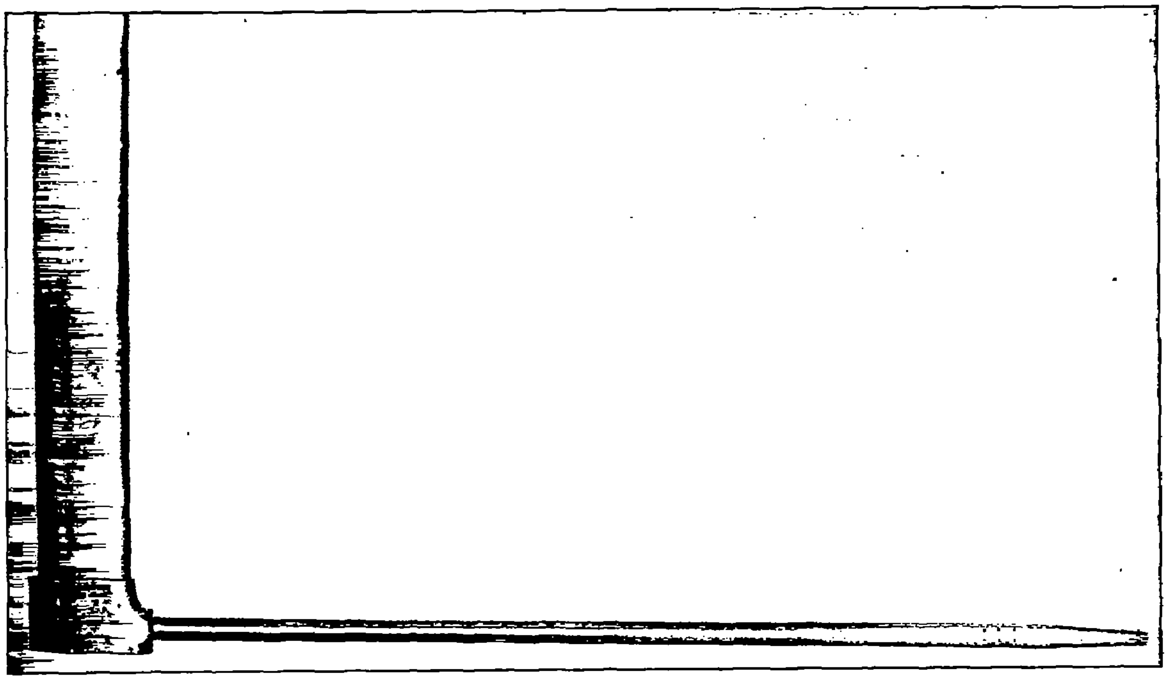

FIG. 1.—BRITISH STANDARD PITOT-STATIC AIR SPEED NOZZLE.

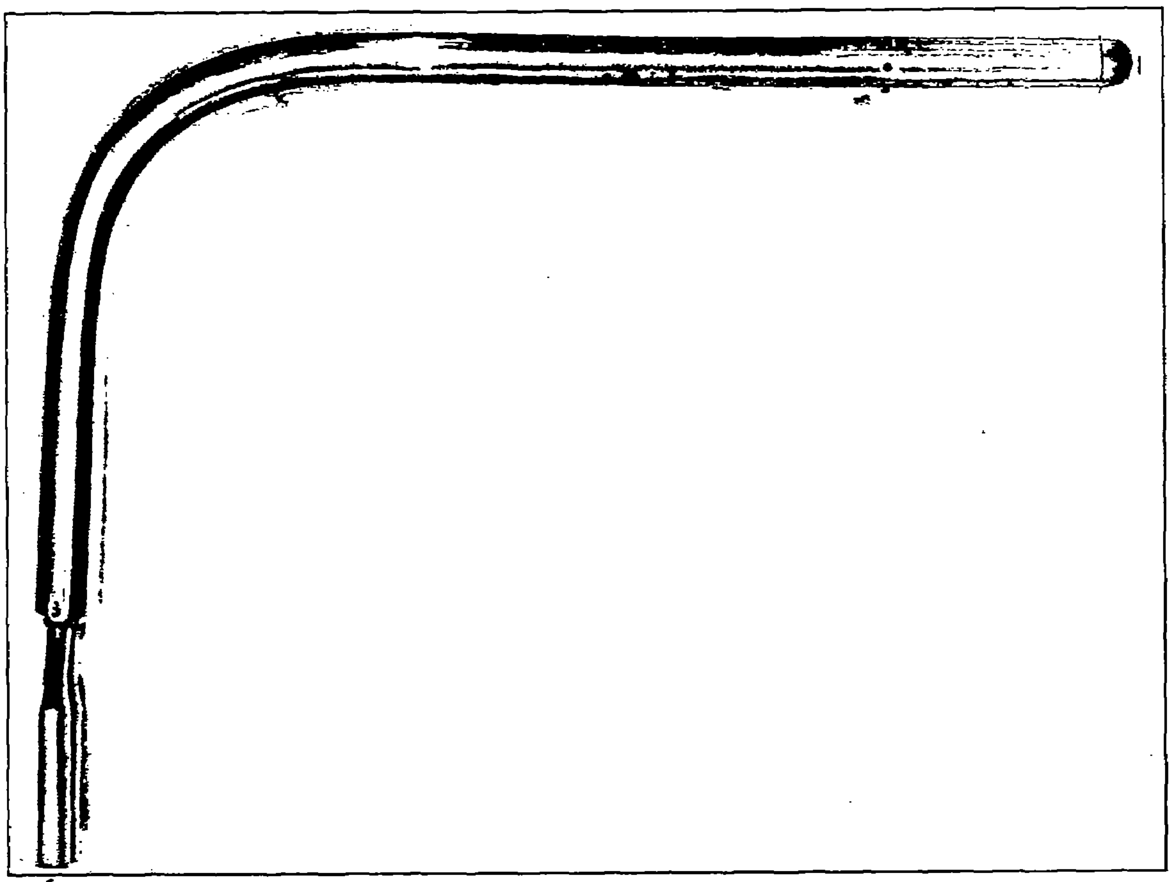

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FIG. 2.—OGILVIE PITOT-STATIC AIR SPEED NOZZLE.

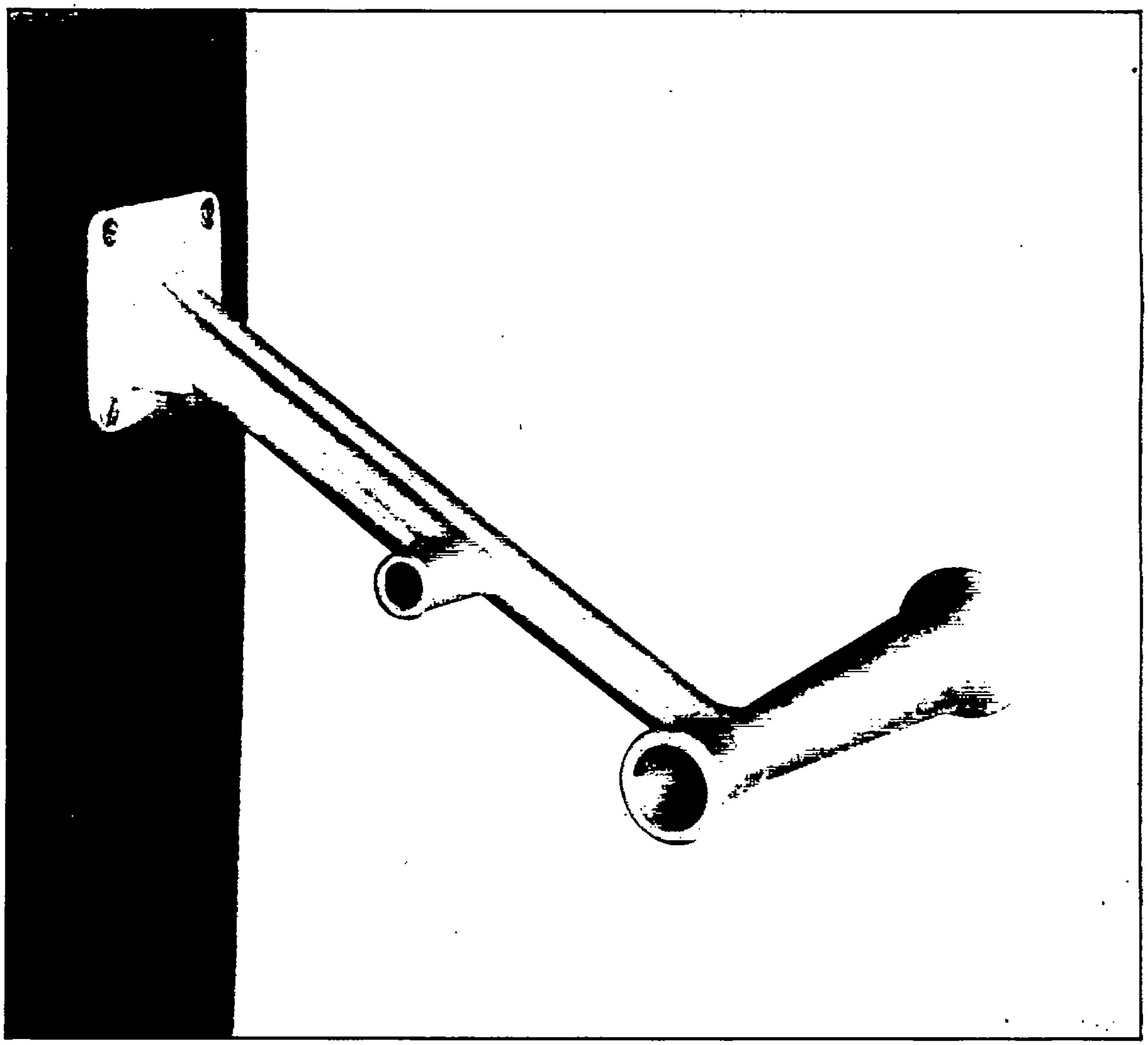

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FIG. 3.—SAND-CAST ALUMINUM PITOT-VENTURI NOZZLE NO. 1.

blows straight through the venturi, generating in its throat a suction many times as intense as said impact pressure. The pressure and suction are transmitted through their respective ducts to the two nipples at the strut, and thence through tubing to a differential pressure gauge on the pilot's instrument board. The gauge is so graduated as to give the true speed through air at normal density.

Theory.—The gauge of a pitot-venturi is actuated by the difference of the pressures at the pitot mouth and the venturi throat. The first pressure increases indefinitely with the speed; the second decreases at first nearly as the square of the speed, then somewhat asymptotically toward zero. An adequate theory should give true mathematical expression to those pressures.[1]

For all speeds the total pressure in the pitot mouth may be written, for adiabatic compression,

$$p = p_o\left(1 + \frac{(\gamma-1)}{2\,\gamma}\frac{\rho_o V^2}{p_o}\right)^{\frac{\gamma}{\gamma-1}} \tag{1}$$

in which p_o, v, ρ_o, are the pressure, speed, and density in the unchecked stream, and $\gamma = 1.405$. From this the "full impact" pressure at any speed is

$$p - p_o = \rho_o V^2/2 + \tag{2}$$

in which the terms after $\rho_o V^2/2$ are, to within 1 per cent accuracy, negligible for all speeds below 155 miles an hour. Table I shows this. For the present experiments ρ_o is taken as the air density at 30″ mercury, 70° F., and 70 per cent humidity; i. e., 0.07465 lbs. cu. ft., this being the standard used prior to 1919. In Table I the new standard density is used.

TABLE I.—*Pressure of air on coming to rest from various speeds, computed from formula.*[1]

Air speed in in meters per sec.	Barometric plus impact pressure in megadynes/sq. cm.		Impact pressure in mm. of water. 1 megadyne/sq. cm.=10206.72 mm. of water.		Percentage difference.
	Incompressible $p=1+\frac{\rho_0 V^2}{2}$	Adiabatic $p=(1+.0000017636\,1V^2)^{3.47}$	Incompressible.	Adiabatic.	
0	1.000000	1.000000	0.00	0.00	0.00
10	1.000612	1.000612	6.25	6.25	0.00
20	1.002446	1.002448	24.97	24.99	0.08
30	1.005504	1.005514	56.18	56.28	0.18
40	1.009784	1.009817	99.86	100.20	0.34
50	1.015288	1.015369	156.04	156.87	0.53
60	1.022014	1.022185	224.69	226.44	0.78
70	1.029964	1.030282	305.83	309.08	1.07
80	1.039136	1.039680	399.45	405.00	1.39
90	1.049532	1.050406	505.56	514.48	1.76
100	1.061150	1.062486	624.14	637.78	2.18
200	1.244600	1.266600	2,496.56	2,721.11	9.00
200	1.550350	1.666557	5,617.27	6,803.36	21.11
400	1.978400	2.367319	9,986.25	13,955.84	39.75
500	2.528750	3.548021	15,603.53	26,006.94	66.67

[1] $p = p_0\left(1+\frac{(\gamma-1)\rho_0 V^2}{2\gamma p_0}\right)^{\gamma/\gamma-1}$
$= (1+00000176361V^2)^{3.47}$
p_0 = 1 megadyne/sq. cm.
ρ_0 = 001223 gm./cu. cm.
γ = 1.405
V = meters/second.
1 megadyne/sq. cm. = 10206.72 mm. of water.
g = 980.6 dynes
t = 15° C. water temperature.

A true theory of the venturi part should treat of both the outer and inner flow along the tube. For the outer flow no mathematical expression is available, and none is here attempted; for the inner flow there is an orthodox theory based on Bernouilli's equation and the principle

[1] The pitot and venturi tubes have an extensive literature. A sufficient account of their history and orthodox "internal" theory, but nothing of their "external" theory is given in report No. 2 of the National Advisory Committee for Aeronautics.

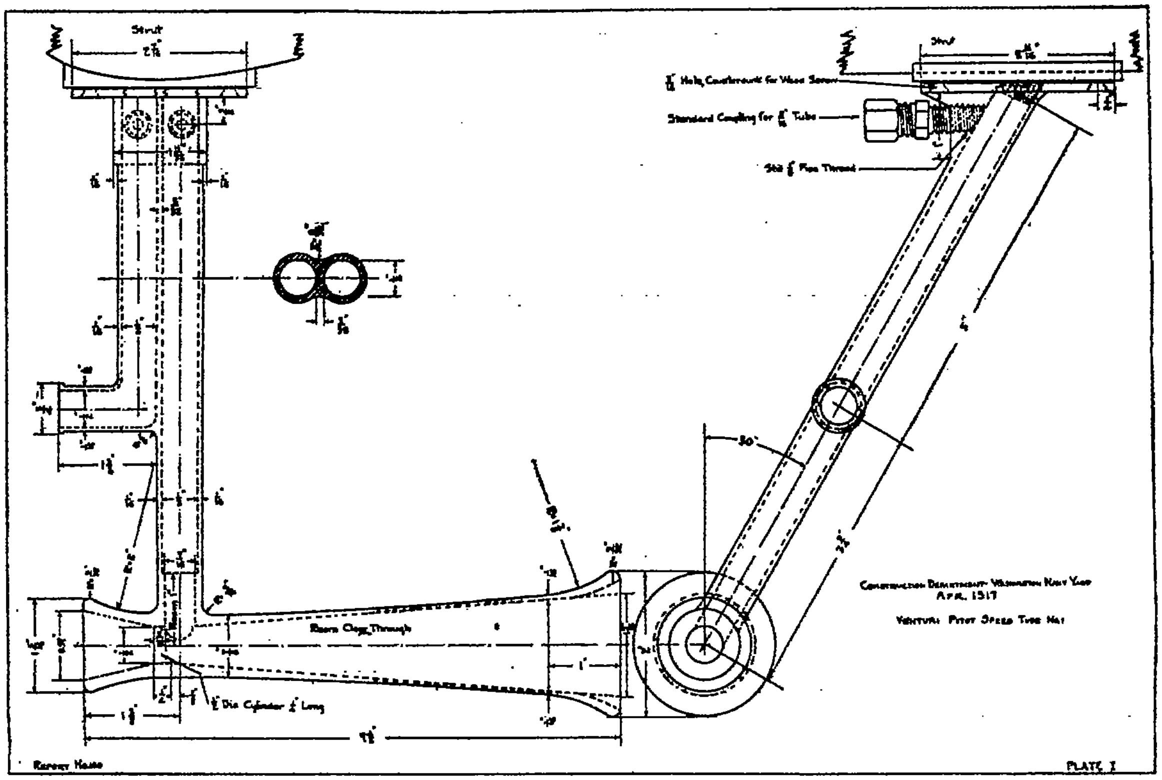


FIG. 4.—WORKING PLANS FOR PITOT-VENTURI NOZZLE NO. 1.

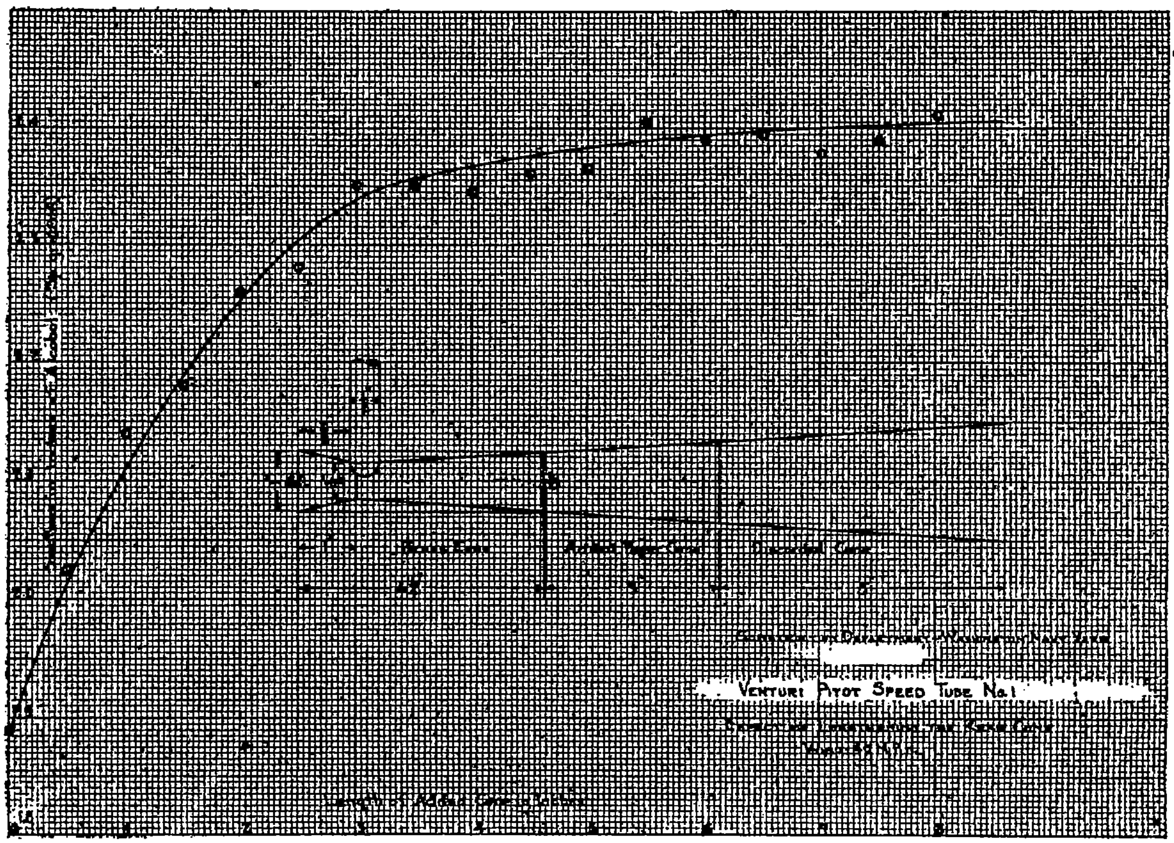


FIG. 5.—SUCTION INCREASE WITH LENGTHENING OF REAR VENTURI CONE.

of continuity. It teaches that, for all airplane speeds for which the air compression is negligible, the mean velocity through the tube varies inversely as the cross-sectional area; also that the change of pressure along a stream line is proportional to the change of the velocity square. This theory may be valid for the flow entirely within a suitably designed tube, but indicates nothing as to the speed of entry or pressure of exit of the air. It is obvious that the speed of entry at the front cone depends on the suction outside the base of the rear cone.

Design data.—To employ experiment in lieu of theory, a short venturi of usual inside proportions, as shown from *a* to *b* in Figure 5, was taken as a starting base. This was lengthened by inserting in its rear a paper cone which could be shortened by clipping off successive segments. The resulting curve given in the diagram shows that the suction steadily increased with length of cone up to an elongation of 3 inches, after which the gain was immaterial. This 3-inch extension was adopted in the finished design. The base of the cone was now flared trumpetwise by adding wax and thus acquired 10 per cent greater suction. The front cone was not improved but rather injured by lengthening or flanging. Table II portrays the loss of suction as the front cone is lengthened; also the gain as the rear cone is lengthened.

Having thus found suitable main dimensions for the tube, some attention was given to the throat and side duct leading therefrom. A cylindrical throat all across the duct gave much less suction than one extending aft only half across the duct. A large duct gave slightly less suction than a small one, but had the advantage of being waterproof. This waterproofness is illustrated by Table III, presenting experimental data which show the pressure required to burst clean water films from the ends of brass tubes of various sizes.

TABLE II.—*Suction in throat of venturi-pitot No. 1, for various lengths of front and rear cones, at 40 miles an hour.*

Length of cone in inches.	Suction in inches of water.
Front cone:	
1.00	1.89
1.25	1.85
1.50	1.83
1.75	1.82
2.00	1.81
Rear cone:	
5.00	1.69
5.50	1.76
6.00	1.82
6.50	1.87
7.00	1.90
7.50	1.93
8.00	1.935
8.50	1.94
9.00	1.95
9.50	1.955
10.00	1.96

TABLE III.—*Bursting pressure for water films on end of clean brass tubes 1/32 inch thick.*

	Diameter of tubes, in inches.				
	.1	.2	.3	.4	.5
Bursting pressure, inches of water	.510	.206	.140	.082	.061

On this hint the duct was made 7/16 inch in diameter, the largest size that could be neatly reamed transversely into a half-inch throat, and the smallest that would be waterproof and convenient for die casting or sand coring. The ducts were sloped to shed water that might enter from dashing spray. Varying the throat diameter one-thousandth inch makes a perceptable change in the reading. Hence dirt in the throat causes error, this being greater the smaller the bore. A fine screw, inserted through the throat wall opposite the duct mouth, could be used to adjust the intensity of suction by altering the flow in the throat, but this device was found unnecessary, as the tubes could be so accurately made as to read practically all alike without adjustment.

Manufacture.—For cheapness, speed, and accuracy in making these tubes, three processes were tried—die casting, copper depositing, sand casting with subsequent reaming. Samples so produced and all satisfactory are shown in Figures 3, 6, 7. The die castings were to be made of aluminum or tin alloy at the rate of four per minute with one die, all true to 1/1000 inch inside, and at a remarkably low cost. But after sending a few good samples the manufacturer canceled his contract, owing to the press of other work and the cost of perfecting a suitable die. The samples were die cast in two parts, telescoping together near where the single duct joins the venturi. The sand-cast nozzle is accurately reamed in its venturi part and where its duct enters the throat; at the flange end it is tapped for nipples, drilled for clamp screws, plugged at the outer ends of its ducts. The copper-deposited tubes were accurate without reaming, and had the advantage of resisting sea water better than the cast tubes, which, for lightness, were made of aluminum. The copper nozzle was made in three parts soldered together—a cast flange, the pitot mouth and duct, the venturi and its duct. The pitot and the venturi each was formed by copper plating soft metal cores which had been cast in very accurate steel dies and could easily be melted out of their copper coats. The aluminum and the copper nozzles each weighed about 12 ounces, the latter having much thinner walls. Smaller sizes were made subsequently, partly for lightness, partly for lessening the air resistance. But these could not be cast all in one piece. Hence the ducts were made of narrow-drawn tubes joining the venturi and flange as had been done with the earliest experimental nozzles made during this study.

Calibration for head-on velocity.—The nozzle No. 1 was calibrated first in the wind tunnel, then in an airplane flying over a measured course. In the tunnel the tube to be tested was placed beside the standard Navy pitot in a uniform wind held at various fixed speeds. The differential pressures in both nozzles were read on alcohol manometers. The true speed was assumed to be given by the standard tube on application of formula (2). The differential pressure readings of the venturi-pitot were then plotted against the computed speed, and used to graduate the gauge of the speed meter. In the field test readings were taken of the speed-meter gauge, the air conditions and the time over a measured course with and against a light breeze. The gauge readings were then plotted against the airplane's speed as computed from the course observations. The error made in ignoring the air's compressibility may be judged from Table I.

Calibration data for graduating the pressure gauges of air-speed meters using nozzle No. 1 are given in Table IV. It was formed from careful tests, in the 4′ by 8′ tunnel, of several copper and several aluminum tubes, at all speeds from 30 to 150 miles an hour. It indicates that the pressure difference increases closely as the square of the speed from 30 to 130 miles an hour, after which it increases less rapidly, if the Navy standard pitot be true. The standard pitot-static nozzle of the United States Navy differs slightly from the British standard in size and shape, but gives the same differential pressure at all speeds from zero to more than 160 miles an hour.

TABLE IV.—*Calibration data for speed nozzle No. 1.*

[Air density=.07465 lbs. cu. ft.]

Air speed miles an hour by Navy pitot.	Differential pressure in inches of water.	Component pressures.	
		Pitot.	Venturi.
30	2.72	0.43	−2.29
40	5.02	0.76	−4.26
50	7.89	1.18	−6.71
60	11.55	1.70	−9.85
70	15.80	2.33	−13.47
80	20.60	3.04	−17.56
90	26.10	3.85	−22.25
100	32.25	4.75	−27.50
110	39.10	5.75	−33.35
120	46.00	6.85	−39.15
130	53.10	8.07	−45.03
140	60.05	9.37	−50.68

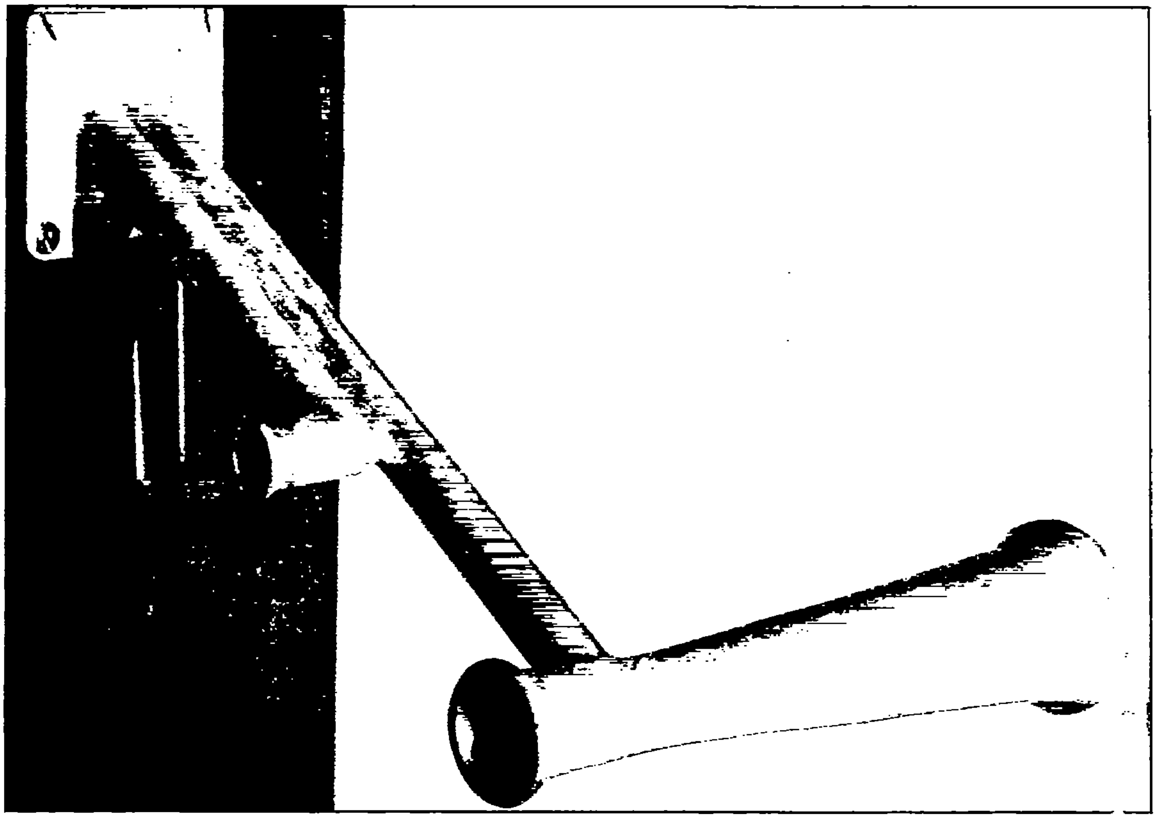


FIG. 6.—DIE-CAST ALUMINUM PITOT-VENTURI NOZZLE NO. 1.

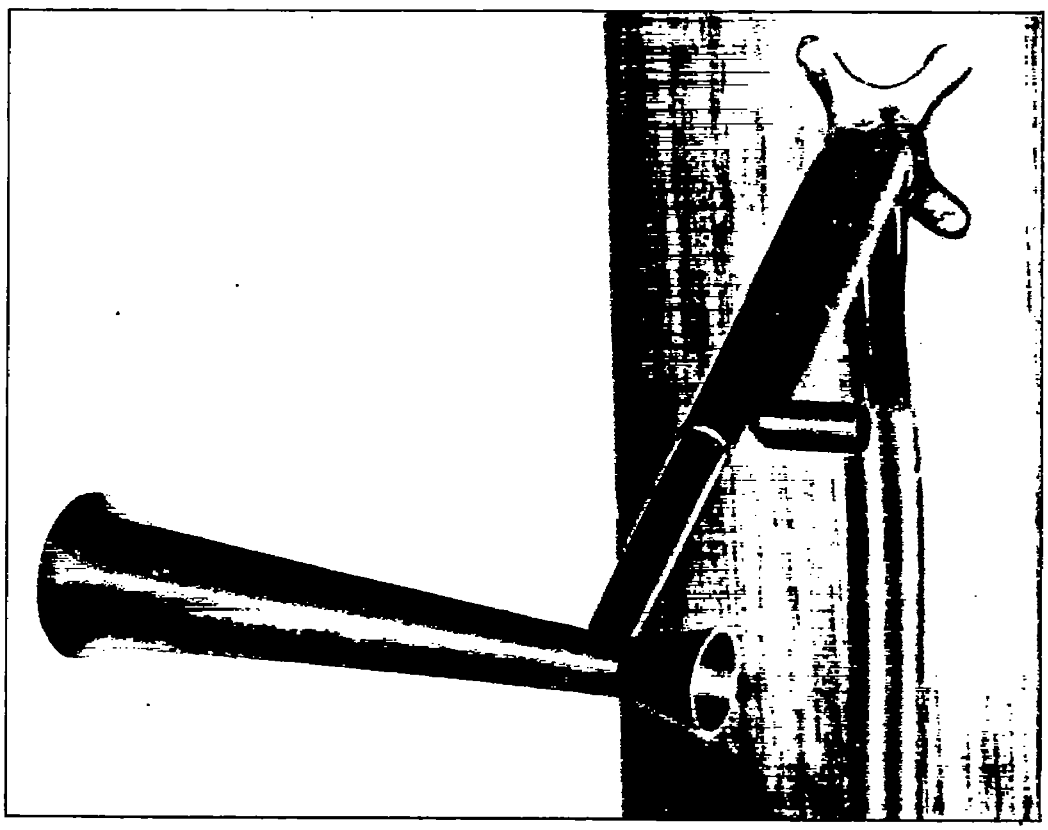


FIG. 7.—COPPER-DEPOSITED PITOT-VENTURI NOZZLE NO. 1.

The reamed aluminum tubes made from sand castings, and unreamed copper-deposited tubes, gave, in the wind-tunnel tests at 60 miles an hour, air-speed readings agreeing with the standard venturi-pitot to a fraction of 1 knot. This is illustrated, for 20 samples of each kind in Table V taken from the routine inspection records made at the Washington Navy Yard to check the inspection tests at the factory. The few die-cast samples, though unreamed, exhibit a like accuracy and about the same values. Their calibration line presented in Figure 18 is for tubes not yet given structure inspection.

TABLE V.—*Inspection test readings of speed-nozzle No. 1 for head-on speed in wind tunnel.*

[True air speed, 60 knots.]

Aluminum nozzle serial number.	Indicated wind speed in knots.	Copper nozzle serial number.	Indicated wind speed in knots.
1969	59.9	1794	59.2
1970	59.3	1795	60.2
1971	59.9	1796	59.2
1972	59.9	1797	60.7
1973	59.9	1798	61.0
1974	59.3	1799	59.7
1975	60.4	1800	61.2
1976	59.9	1801	60.2
1977	59.4	1802	59.2
1978	60.5	1803	59.7
1979	59.9	1804	59.4
1980	60.3	1805	60.7
1981	60.3	1806	59.7
1982	59.9	1807	60.2
1983	60.9	1808	60.0
1984	59.9	1809	60.2
1985	59.9	1810	59.2
1986	60.5	1811	60.0
1987	59.3	1812	59.2
1988	60.4	1813	61.2
Mean	59.985	Mean	60.05

When a nozzle varies more than 1 knot from the true speed it is rejected, unless retest or a structure inspection shows that the error can be corrected. The fact that the mean reading for many tubes varies less than one-tenth of a knot from the standard, indicates that the individual variations may be test errors rather than structural.

The reports of field tests manifest a fair agreement between the airplane speed indicated by the speed meter and that computed from the mean speed over a measured course. Table VI summarizes the results of such a test made at McCook Field by members of the Instrument Division of the United States Army, with a No. 1 nozzle joined to a Foxboro gauge. The readings of the gauge were corrected for barometric pressure, but not for temperature or humidity.

TABLE VI.—*Summary of airplane speeds as indicated by Nozzle 1 and Foxboro gauge, and computed from time over a measured course.*

Date and meter.	Barometer.	Speed indicated by gauge, m. p. h.	Same corrected for barometer.	Speed from time over measured course.
May 1, No. 261	29.52	117.8	119.7	118.1
May 5, No. 261	29.02	112	115.8	116.8
May 5, No. 261	29.02	116	120	117.5
May 8, No. 720	29.06	118.5	122	120
May 8, No. 659	29.03	125.8	129	126.5
May 8, No. 720	29.02	124	128	129

Calibration in pitch and yaw.—A sample of the No. 1 nozzle was mounted on the side of an airplane strut in the 8′ by 8′ tunnel to find the change of indicated speed caused by pitching and yawing. To produce this change of incidence the strut bearing the nozzle was turned slightly each way about the throat as center. The results are given in Table VII, and show that the indicated speed varies from the true by less than 1 mile an hour as the incidence varies from 8° to −8° in pitch and from 4° to −8° in yaw; that is over a range of 16° in pitch, 12° in yaw.

TABLE VII.—*Indicated speeds for various incidences in pitch and yaw for copper speed nozzle No. 1 in a wind fixed at 40 and 70 miles an hour.*

Incidence.	Pitch.		Yaw.	
	40 miles per hour.	70 miles per hour.	40 miles per hour.	70 miles per hour.
14°	41.4	71.1	40.5	69.5
12°	41.4	71.05	40.6	69.5
10°	40.8	71.0	40.7	69.6
8°	40.65	70.8	40.9	69.7
6°	40.5	70.7	41.2	69.9
4°	40.2	70.25	41.0	70.25
2°	40.1	70.25	40.6	70.25
0°	40.0	70.0	40.0	70.0
−2°	40.1	70.25	40.1	70.05
−4°	40.2	70.35	40.2	70.1
−6°	40.65	70.50	40.6	70.2
−8°	40.8	70.55	40.9	70.4
−10°	41.15	70.6	41.2	70.6
−12°	41.0	70.7	41.3	71.5
−14°	41.0	70.6	41.4	73.0

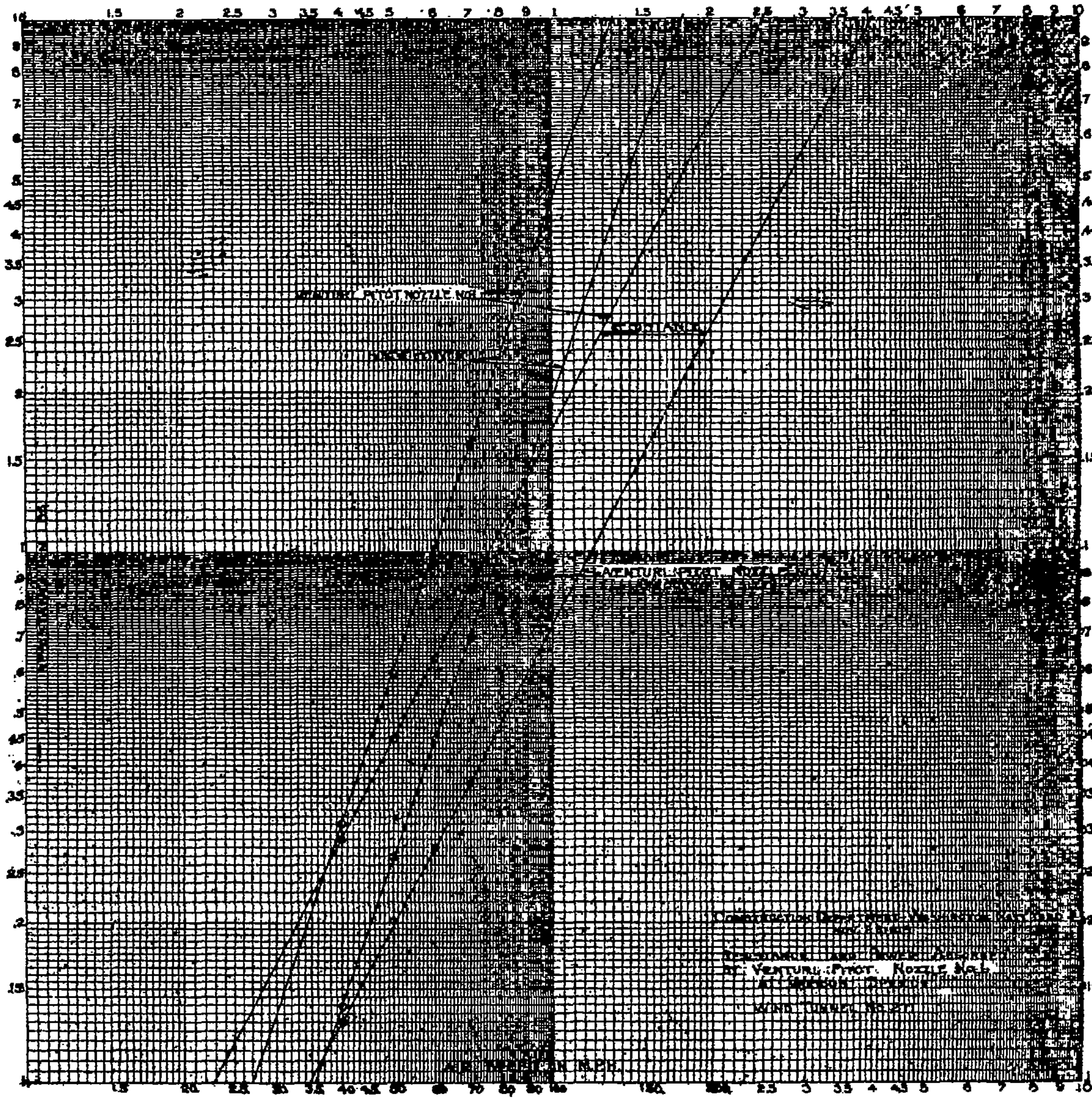


FIG. 8.—RESISTANCE AND ABSORBED POWER FOUND FOR NOZZLES NO. 1, LARGE AND SMALL.

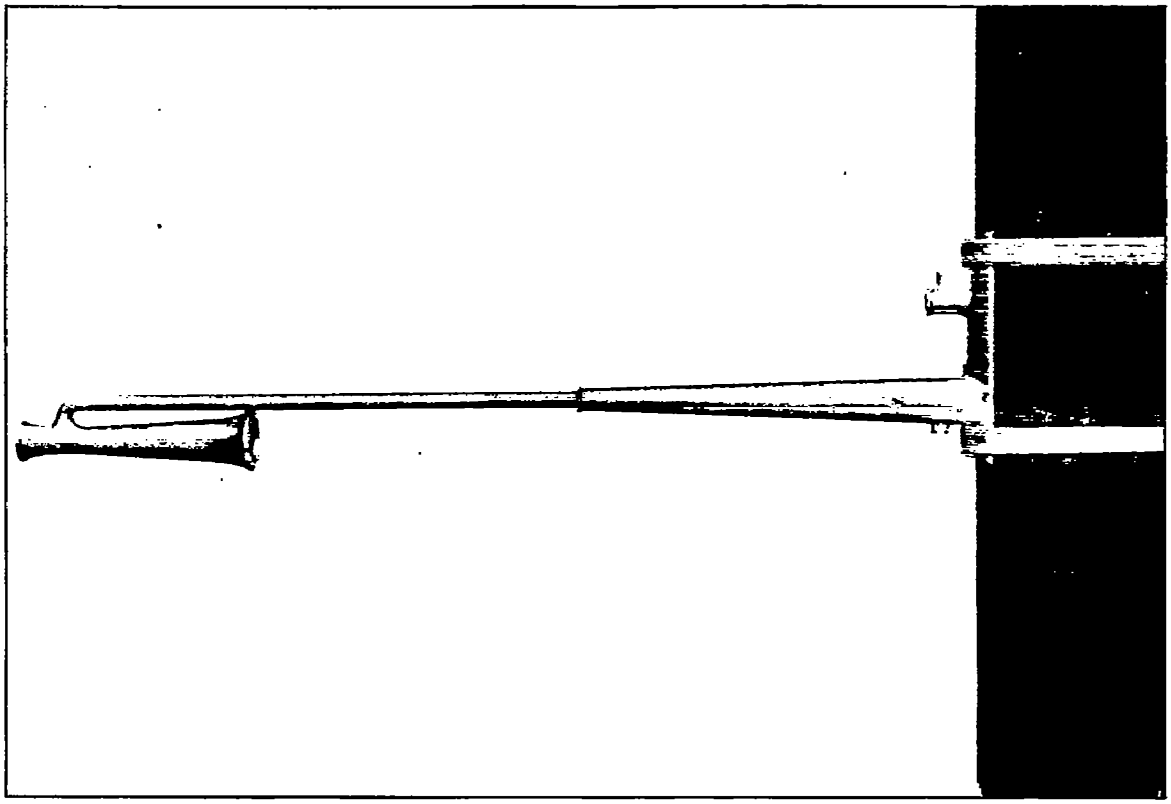


FIG. 9.—GOOSE NECK PITOT-VENTURI NOZZLE NO. 1.

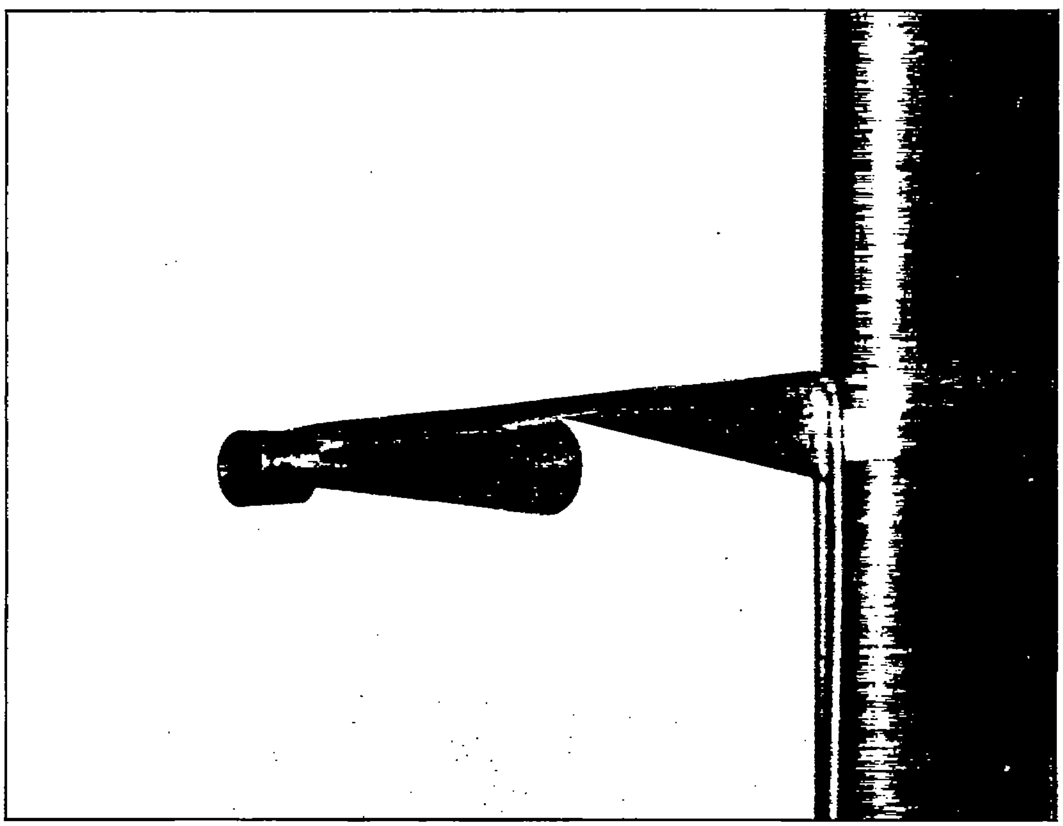


FIG. 11.—FOXBORO PITOT-VENTURI.

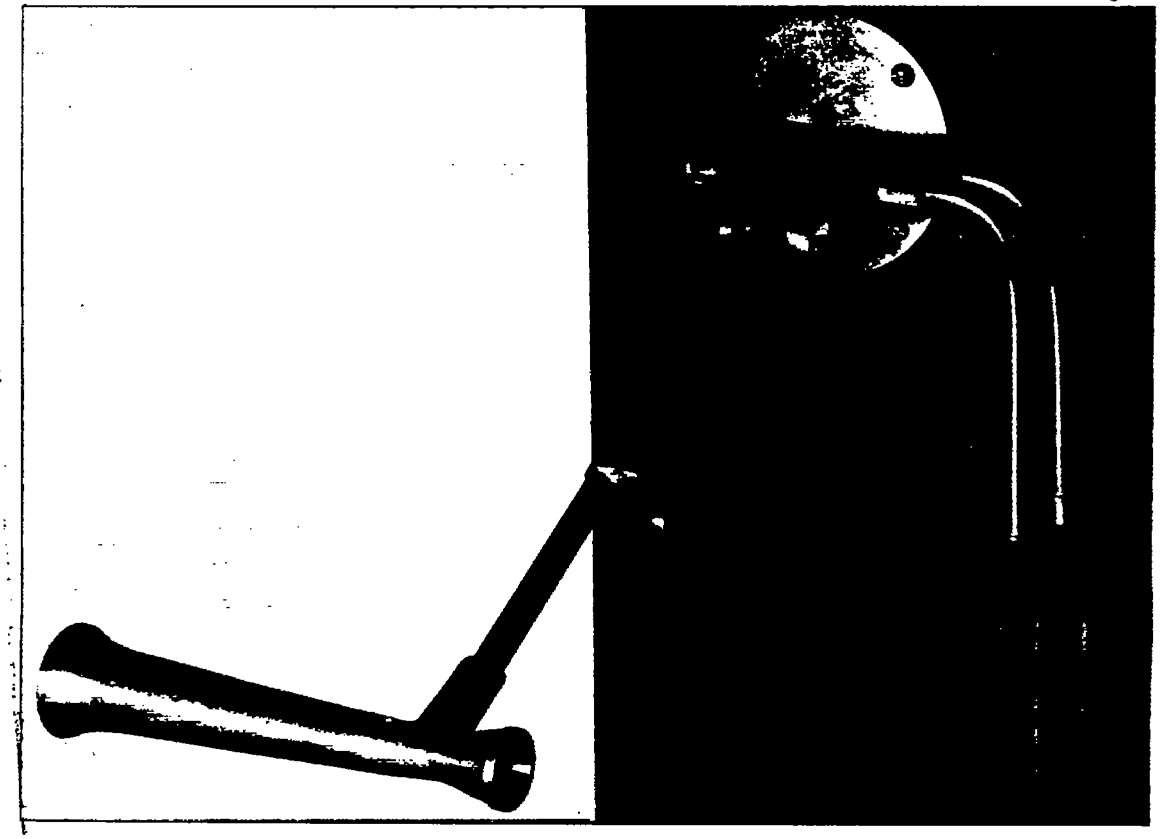


FIG. 12. SMALL-SIZE NOZZLE NO. 1 TYPE.

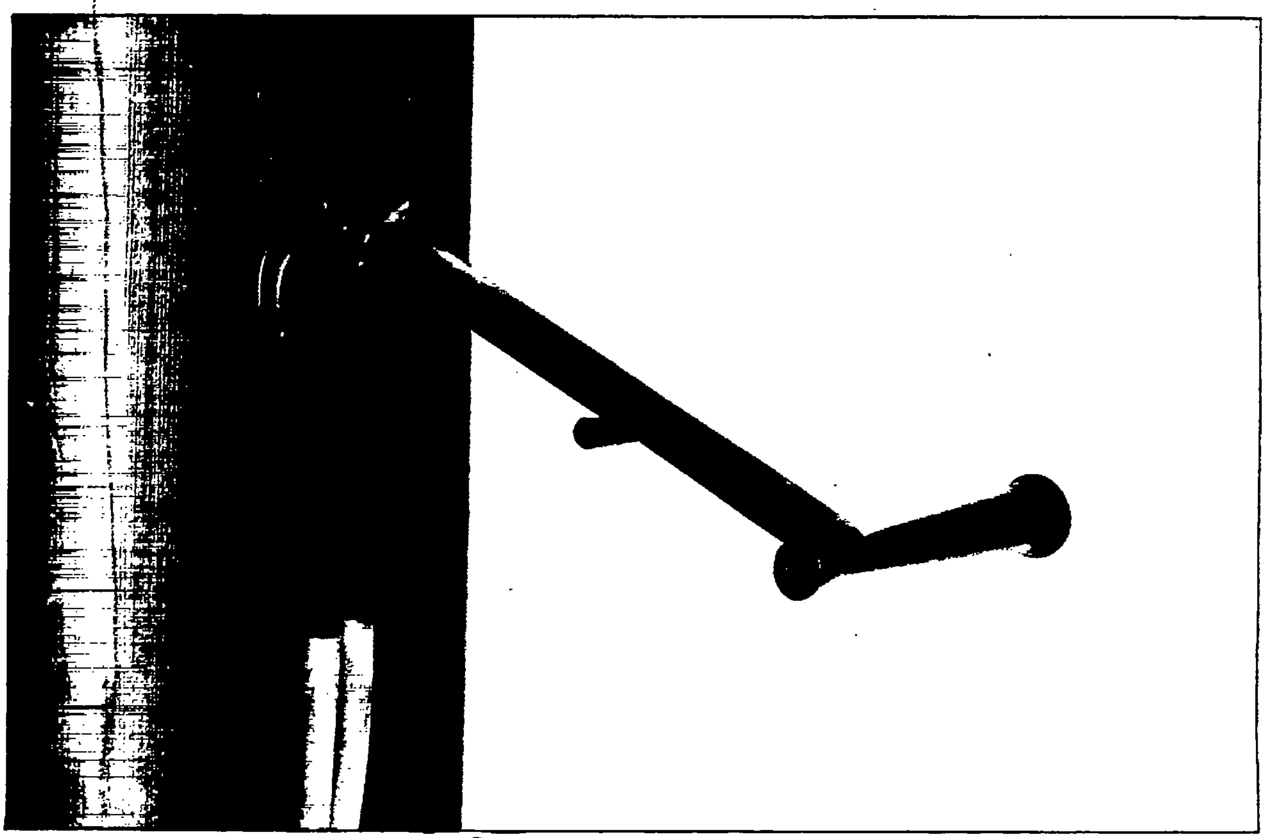


FIG. 13.—COPPER-PRODUCTS CO. NOZZLE NO. 1.

Test for waterproofness.—To ascertain whether in use the tubes would have their side duct coated with a water film, they were first cleaned of oil, then exposed to a spray of hydrant water in the wind tunnel in an air current of 40 miles an hour. In such tests nozzle No. 1 never clogged; the nozzles of other makes, with fine static holes, always clogged by the formation of a film over the apertures. Reports from sea tests also affirm that in practice a film never forms over the seven-sixteenth-inch duct.

Resistance and absorbed power.—The air resistance and horsepower absorbed are given in Figure 8 for nozzle No. 1 and a smaller one of similar make to be described presently. These measurements are to be extended to higher speeds. They indicate that the resistance increases slightly less than as the square of the speed; also that the large tube has rather more than twice the resistance of the smaller. This item is not negligible for small airplanes of highest speed. At 70 miles an hour the small nozzle No. 1 absorbs 0.07 horsepower, the large one 0.16.

MISCELLANEOUS AIRSPEED NOZZLES.

Incidental to the work on No. 1, various other forms of speed nozzle were developed. These had for salient features convenience or suitability of placement, or lightness, or minimum air resistance, etc.

Gooseneck nozzle No. 1.—Figures 9 and 10 illustrate a modified form of nozzle No. 1 designed to protrude forward of a wing strut, so as to encounter less disturbed air, have less resistance, and still have waterproofness and great suction power. The impact or pitot nozzle is close to the strut and joins the up-pointing pressure nipple at the top of the base casting which is lashed fast with cords. The venturi duct rises vertically from the venturi throat, then turns sharply aft some 2 feet, running horizontally through the protruding horn of the base casting to the down-pointing suction nipple. The pitot reads the same whether near to or far before the strut. The venturi, to escape blanketing, must be placed with its base about 2 feet before a 2 by 6 inch strut. The diagram in Figure 10 shows how the venturi loses suction as its base approaches the strut nearer than 2 feet.

The Foxboro venturi-pitot.—Some weeks after the test of the foregoing tube, the Foxboro Co. presented for test the gooseneck venturi portrayed in Figure 11. This nozzle has the merit of lightness, scant resistance, and ample suction power. It consists of an ordinary forward protruding venturi whose front cone is covered with a thin tube of slightly larger diameter, leaving between it and the underlip of the cone a crescent-shaped opening. The under cavity receives the air impact and transmits it around the neck of the cone to the small impact pipe running thence to the pressure gauge. The suction pipe connects with the venturi throat in the usual way. Besides the possible film in the venturi duct, two other features of this nozzle are, (1) it is blanketed by the strut; (2) a heavy spray can easily cause a flooding of the duct of the pitot part.

Small-size nozzle No. 1 type.—Figure 12 portrays a nozzle of about half the linear size of the No. 1, made by the same manufacturer, more especially for the United States Army, and intended to have less weight and air resistance. It was made in the latter part of 1918 under the direction of Maj. C. E. Mendenhall, R. C. A. S. The venturi is a reamed bronze casting; the supporting base is of stamped sheet steel; the remainder is of drawn tubes bent through the base and soldered therein. The ducts, though sloping laterally downward, as in nozzle No. 1, are not waterproof at all airplane speeds, because their lower ends can be clogged with a water film, not perhaps when new and oily, but certainly after aging.

By trial it was found that a film over the venturi duct can withstand a steady resultant pressure of 0.44 of an inch of water. This is 4 per cent of the differential pressure reading at 60 miles an hour, 16 per cent of the reading at 30 miles an hour. A like error may be caused by a film at the mouth of the small-bore pitot part. The two films will usually conspire, thus practically doubling the error due to either. When subjected to a gentle spray of water in the wind tunnel at 45 miles an hour this nozzle promptly gave readings false by over 10 per cent, due to a film in the venturi duct, and a like error due to a film over the pitot mouth. A heavier spray completely filled the pitot duct and its connecting tube, a mishap which in practice would cause an indefinitely large error. No exact data are at hand to indicate how severe the dousing of the pitot is over rough water or in a rainy sky. It must be remembered that the impact of a raindrop is 800 times that of the same volume of standard air.

The readings of this instrument, compared with simultaneous readings of the larger nozzle No. 1, are given in Table VIII, and indicate that for all speeds from 60 to 130 miles an hour a common gauge can be made for the two nozzles that shall indicate the same speed to within less than 1 mile an hour. The two differential pressure columns in Table VIII were obtained

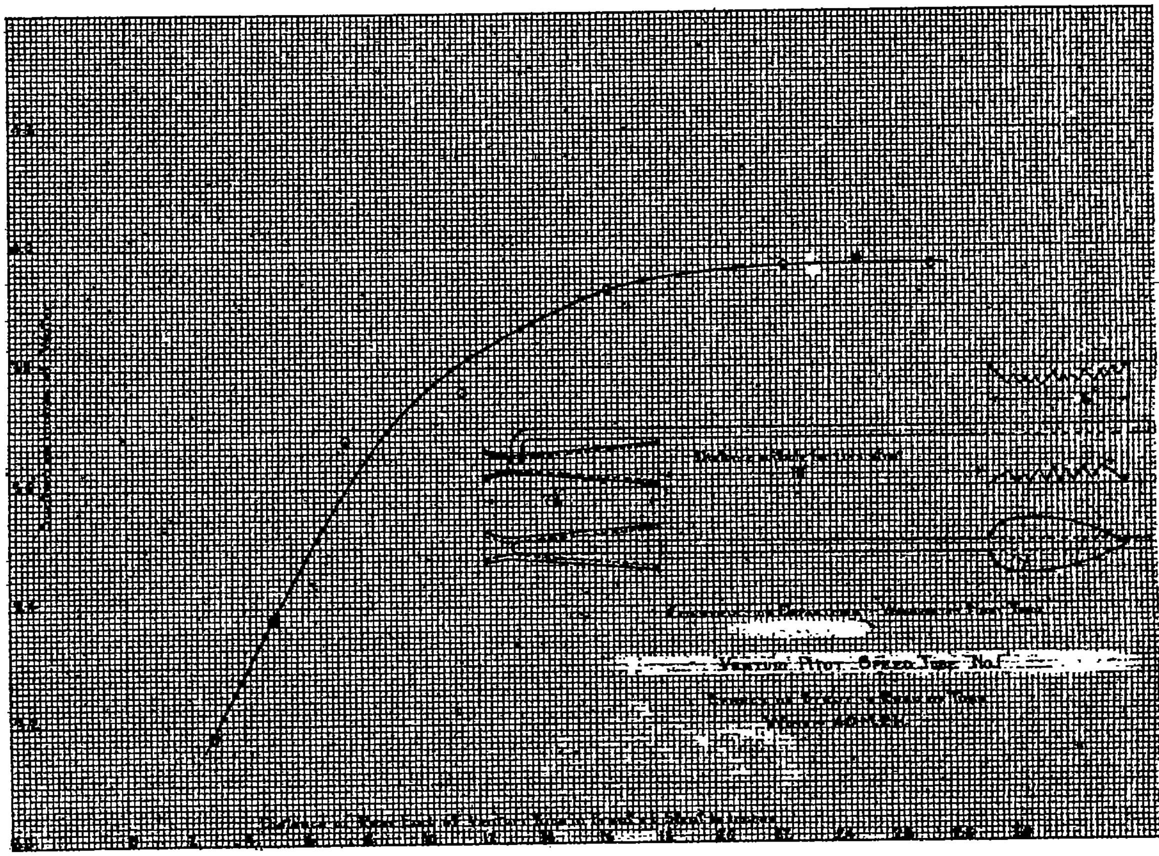


FIG. 10.—EFFECT OF STRUT IN REAR OF VENTURI TUBE.

by two different experimenters in different tunnels with different measuring instruments. The nozzles will be tested together in the same tunnel through a greater range of speeds.

TABLE VIII.—*Differential pressures at various speeds in Nozzle No. 1, large and small types.*

Wind tunnel speed, by standard Navy Pitot, miles per hour.	Differential pressure, inches of water.		Speed difference.	
	Nozzle No. 1, large.	Nozzle No. 1, small.	Per cent.	Miles per hour.
60	11.55	11.00	2.5	1.5
70	15.80	15.20	2.0	1.4
80	20.60	20.05	1.5	1.2
90	25.10	25.40	1.0	.9
100	32.25	31.45	1.2	1.2
110	39.10	38.00	1.3	1.43
120	45.00	45.25	−.7	−.84
130	53.10	53.20	−.1	−.13
140	60.05	61.90	−1.5	−2.10
150		71.10		
160		80.60		

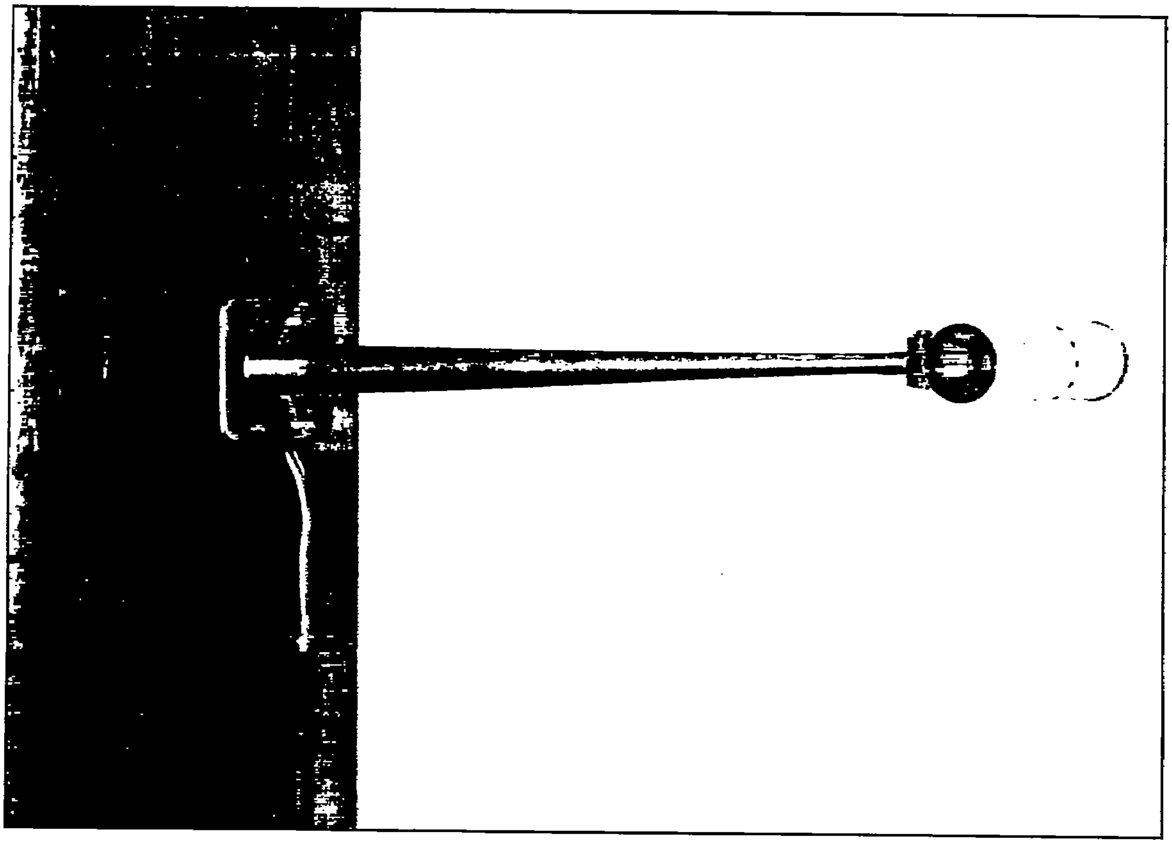
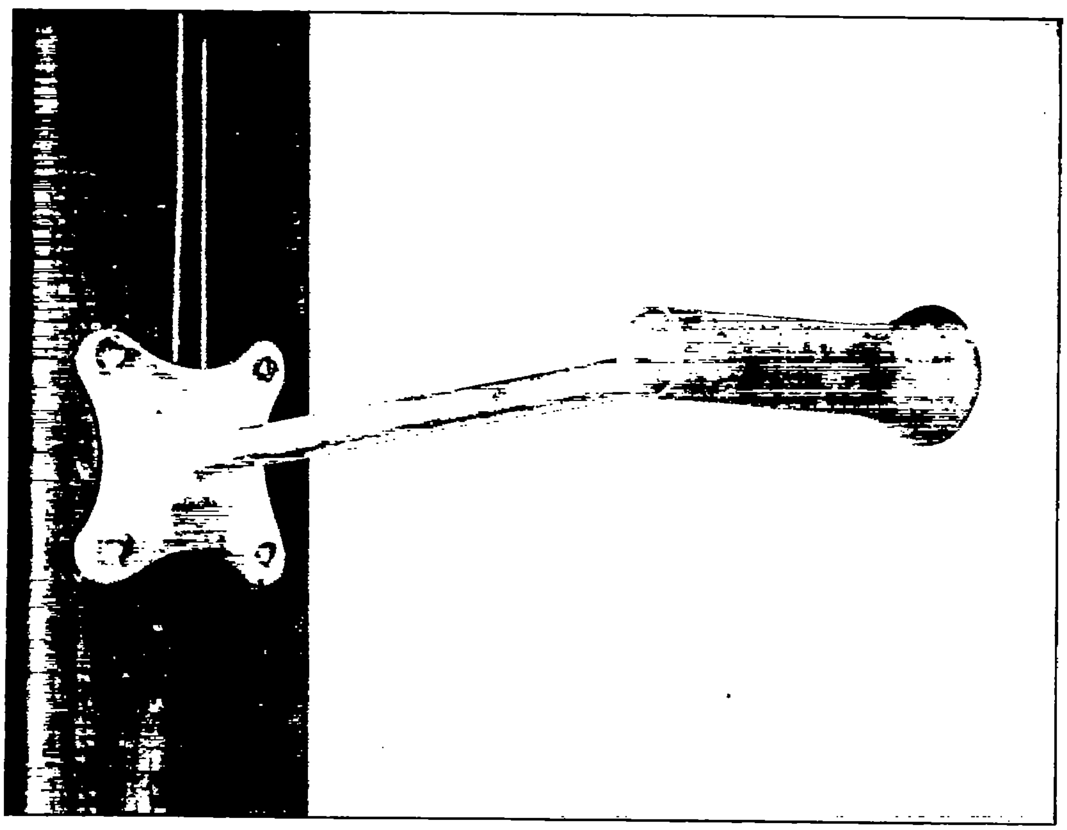


FIG. 14.—SINGLE-THROAT PITOT-VENTURI WITH SMALL FLARE AT REAR.



331—1 FIG. 15.—SINGLE-THROAT PITOT-VENTURI WITH LARGE FLARE AT REAR.

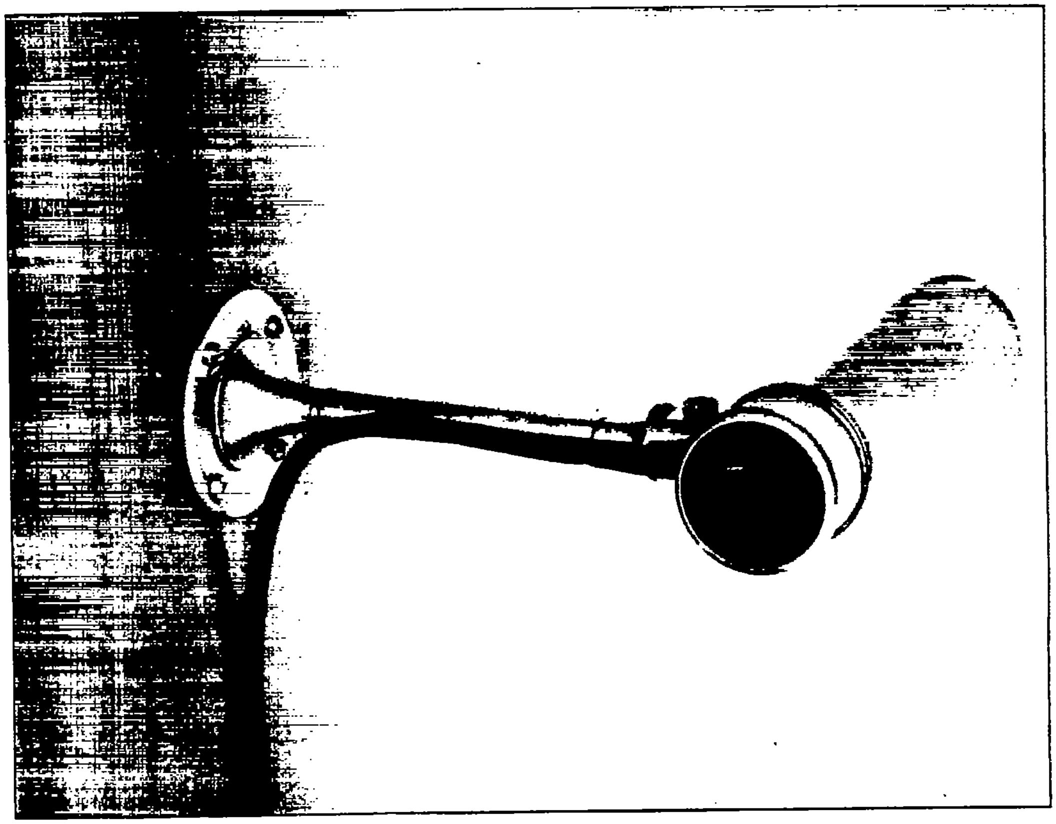


FIG. 16.—BADIN DOUBLE-THROAT VENTURI.

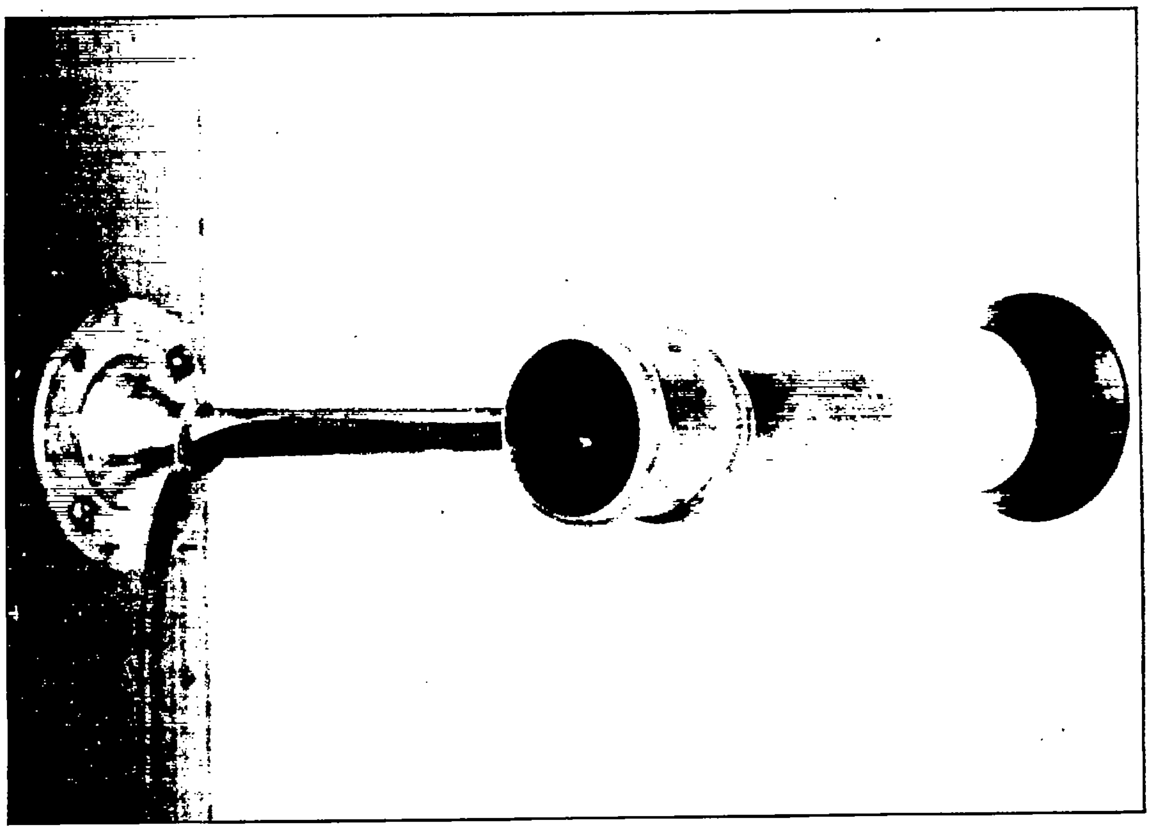


FIG. 17.—BADIN DOUBLE-THROAT VENTURI WITH FLARED END.

Figure 13 shows a small-size nozzle of No. 1 type made by the Copper Products Co. A tetrapod cast-brass flange supports the usual copper-deposited pitot and venturi portions, the pitot stem being of streamline form and covering the venturi stem, which is a small round tube. Both stems are soldered to the venturi neck and to the brass flange. At 60 miles an hour this nozzle reads the same to within a fraction of 1 mile, as the airstream varies in pitch and yaw through 10° positive and negative.

Small French-type single throat pitot-venturi.—Figure 14 shows a French pitot-venturi which normally has a cylindrical tube too slightly flared in its rear, and which, in the present study, was flared like that in nozzle No. 1, to ascertain the increase of head so obtainable. Table IX gives the suction readings for both the original venturi part and the more flared form, and indicates that the latter shape is 50 per cent the more effective. Further increase of flare did not improve the suction.

TABLE IX.—*Suctions in inches of water for slightly flared and more flared venturi.*

Wind speed, miles per hour.	Conditions of tube.	
	Slightly flared.	More flared.
30	1.97	2.81
35	2.70	4.01
40	3.52	5.01
45	4.45	6.65
50	5.50	8.15
55	6.65	10.00
60	7.95	12.15
65	9.35	14.25

The French instrument was composed of many parts, the stem being a folded brass sheet soldered to its supporting flange and bolted to a lug on the venturi, while the latter element was composed of four separate parts. A similar instrument, developed in this study, with its body, stem, and flange cast in one piece, is shown in Figure 15, and weighs slightly over 2 ounces. Its stem was intended to have a form of minimum resistance. Both instruments have detachable front cones, and both have very fine ducts, hence are not water-proof. Their readings approximate those of nozzle No. 1.

A water-proof pitot.—For awhile there was some demand, for use on very fast airplanes, for a speed nozzle whose impact mouth should be as usual, but whose other member should give the true barometric pressure of the undisturbed air. To that end a thin-walled $\frac{1}{2}$-inch cylinder, provided with the usual $\frac{1}{16}$-inch side duct was substituted for the venturi part of speed nozzle No. 1. By coning its rear end inward or outward, the cylinder could be made to give, in the side duct, either the true barometric pressure or a considerable excess or defect thereof. This new nozzle was, of course, water-proof.

A high-suction venturi.—To furnish power for a gyroscope there has been need for a nozzle giving stronger suction than is conveniently attainable with ordinary nozzles. The need was met by attaching a tiny single-throat venturi at each of two opposite tips of a small windmill having hollow spokes joined to a hollow shaft, the venturi axes pointing in the direction of the relative air velocity. In a wind of 60 miles an hour the suction was 52 inches of water, with zero volume delivery, and less as the volume delivery increased. The suction was, in fact, about twice that of a good double-throat flared venturi, and about four times that of a well flared single-throat one, as may be inferred from Tables IX, X.

DOUBLE-THROAT AIRSPEED NOZZLES.

For slow-speed air-craft a nozzle more powerful than the single-throat venturi seemed desirable. It was therefore sought to render water-proof a double-throat venturi of known design.

Badin double venturi.—Figures 16 and 17 show a Badin venturi of good design, with and without flared rear, and without pitot accompaniment. Table X gives its suction readings for both forms at various speeds. The flare increases the reading about 20 per cent, and at 60 miles an hour makes it 2.8 times the suction alone of nozzle No. 1.

TABLE X.—*Suction of flared and unflared Badin double venturi, in inches of water.*

Air speed, miles per hour.	Original Badin venturi.	Same with rear end flared.
20	1.95	2.34
30	4.85	5.70
35	6.80	8.75
40	9.10	11.30
45	11.80	14.80
50	14.90	18.05
55	18.40	22.15
60	22.30	26.55
65	26.60	32.45
70	31.20	36.15

Hooded double-throat pitot-venturi.—To render the Badin speed nozzle waterproof, while still retaining much of its suction power, it was transformed into the instrument depicted in Figures 18 and 19. In principle it now consists of an ordinary double-throat venturi reversed in direction, its smaller end inserted in a dry-air cistern, its larger end capped with a tee-tube which serves both to increase the suction and to shield the venturi from rain.

The wind driving into the rectangular slot of the cistern strikes a wire screen and dashplate designed to remove the raindrops; thence passes upward, then forward through the regular venturi; thence into the tee pipe, where it divides right and left, finally emerging from rectangular slots at the rear thereof. The impact pressure is collected from a nipple at the top of the cistern, as shown. A tube leading from the throat of the smaller venturi collects the suction. The base of the instrument is provided with lugs for attachment to a pole protruding from the car or rigging of a dirigible.

Figure 19 presents the calibration curve of this instrument for all speeds from 20 to 70 miles an hour; also that of the standard die-cast nozzle No. 1, for comparison. In both the resultant pressure difference varies directly as the square of the velocity at speeds from 30 to 70 miles an hour, the highest available in the 8′ x 8′ tunnel.

Table XI presents the indicated speeds in a 40-mile wind at all incidences in pitch and yaw from 0° to 10° positive and negative. The yaw column indicates no variation in speed for changes of incidence from 0° to 10°; the pitch column indicates an increase of less than one-fourth mile per hour as the nose of the instrument is canted up 7° and a decrease of less than 1 mile per hour as it is canted down 7°. This latter variation is doubtless due to the blanketing of the rectangular slot of the cistern, and might be obviated by lowering the slot.

TABLE XI.—*Indicated air speed in pitch and yaw with hooded double venturi, wind speed in tunnel 40 miles per hour.*

Angle of venturi axis to wind.	Readings in pitch.	Readings in yaw.
10	40.5	40.0
8	40.3	40.0
6	40.15	40.0
4	40.0	40.0
2	40.0	40.0
0	40.0	40.0
−2	39.8	40.0
−4	39.5	40.0
−6	39.3	40.0
−8	39.0	40.0
−10	38.8	40.0

The tee-cap alone in a 40-mile wind was found to exert a constant suction as it pitches and yaws 8° either way from the head-on direction. This in a measure corroborates the results published by Drs. Finzi and Soldati, in 1902, in their pamphlet "Esperimenti Sulla Dinamica dei Fluidi," in which they show that the pressure distribution over the rear surface of a cylinder held squarely across the wind is constant. They gave no readings, however, for a cylinder held oblique to the wind. The present study indicates also that the pressure distribution all around a cylinder is practically the same when the axis is normal to the wind as when at 80° or 85° thereto. This fact was noted when using a perforated cylinder as an incidence meter in the tunnel to find the wind direction, as suggested by those two experimenters and later tried by others. Table XII gives the pressure distribution so found.

TABLE XII.—*Air pressure distribution around a cylinder placed across a uniform air stream. Cylinder five-eighths inch diameter; perforation in its side 1 millimeter in diameter and 6 inches from its end; air speed 40 miles an hour; air density 0.07465 pound per cubic foot.*

Inclination of wind to axis of hole inside of cylinder (degrees).	Kinetic pressure at side hole in inches of alcohol. Specific gravity of alcohol, 0.829.		
	Inclination of cylinder, (90° to wind).	Inclination of cylinder, (85° to wind).	Inclination of cylinder, (80° to wind).
0	1.015	1.020	1.015
1	1.015	1.020	1.020
2	1.015	1.020	1.015
4	1.000	1.000	1.000
6	.985	.985	.990
8	.965	.965	.965
10	.935	.935	.935
12	.895	.900	.900
14	.850	.845	.850
16	.795	.795	.805
18	.750	.745	.750
20	.675	.670	.685
22	.610	.600	.615
24	.525	.525	.540
26	.450	.445	.465
28	.370	.360	.380
30	.280	.270	.290
35	.040	.050	.060
40	−.200	−.200	−.175
45	−.435	−.435	−.410
50	−.660	−.660	−.635
55	−.860	−.855	−.825
60	−1.010	−1.010	−.975
65	−1.100	−1.100	−1.065
70	−1.115	−1.120	−1.100
75	−1.080	−1.090	−1.065
80	−1.030	−1.030	−1.030
85	−.950	−.960	−.965
90	−.925	−.930	−.920
100	−.900	−.905	−.900
110	−.910	−.910	−.900
120	−.920	−.920	−.910
130	−.935	−.935	−.930
140	−.940	−.945	−.935
150	−.960	−.960	−.955
160	−.965	−.970	−.965
170	−.975	−.980	−.970
180	−.990	−.980	−.965
190	−.990	−.990	−.965

A few of these instruments were manufactured and installed on motor balloons. Later, owing to the cost and difficulty of uniform manufacture, they were discarded in favor of the single-throat speed nozzle No. 1 coupled with a delicate pressure gauge.

Conclusion.—As the purpose of this study was merely to develop a practical waterproof speed nozzle for immediate use, a summary of the general properties of such tubes need not be given, further than has been done incidentally in the text. Such general properties have been detailed many times by earlier experimenters. It suffices to note that the large-size nozzle No. 1 is waterproof and that it gives true readings at all ordinary angles of incidence and at all speeds up to more than 2 miles per minute. For very swift machines of moderate power a nozzle of less resistance must be used, even though not waterproof. But with some attention to structural details it is practicable to make both tubes give true speed readings when joined in turn to the same pressure gauge.

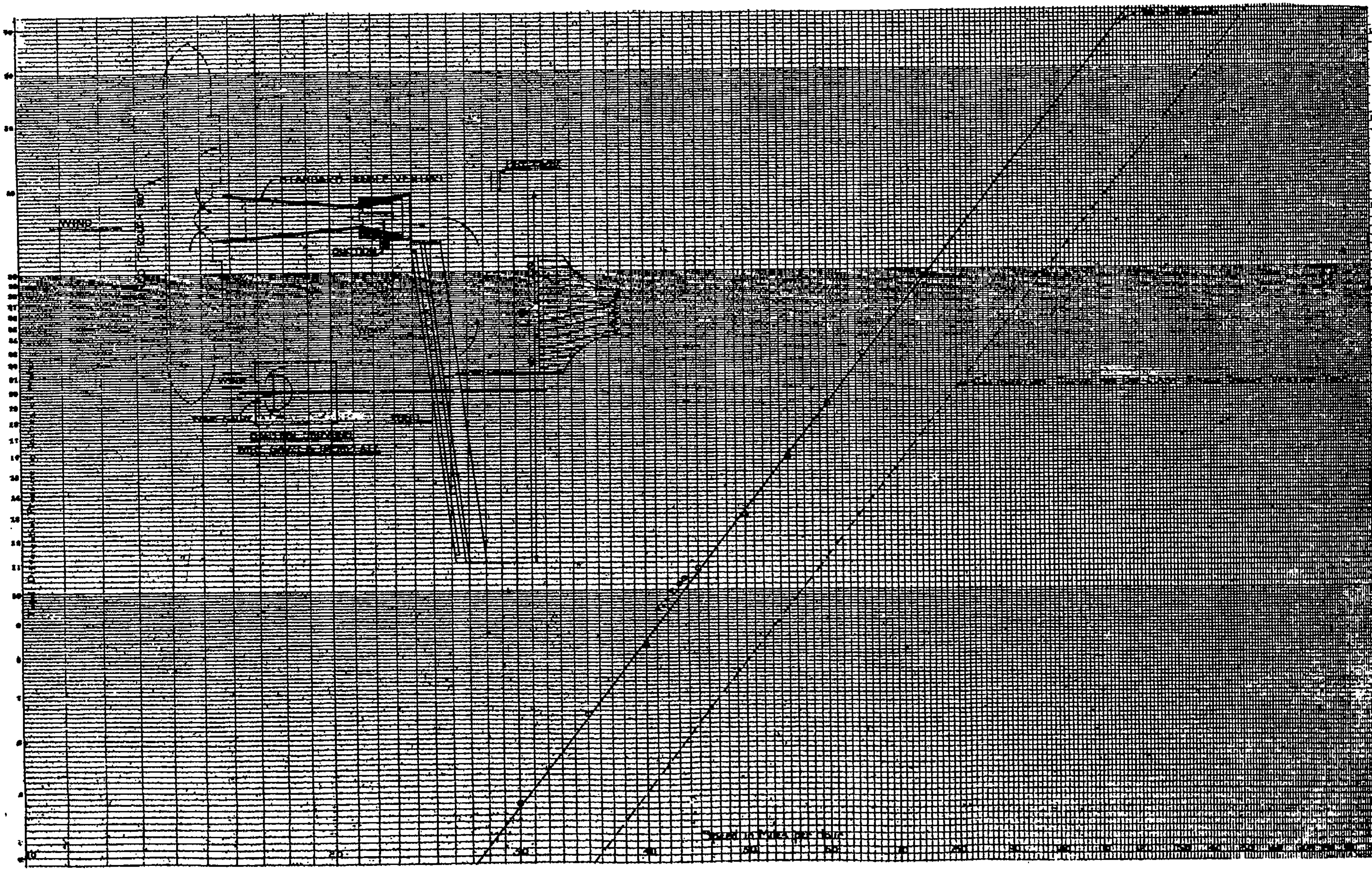


FIG. 19.—PLAN AND CALIBRATION CURVE FOR HOODED DOUBLE-THROAT PITOT-VENTURI.

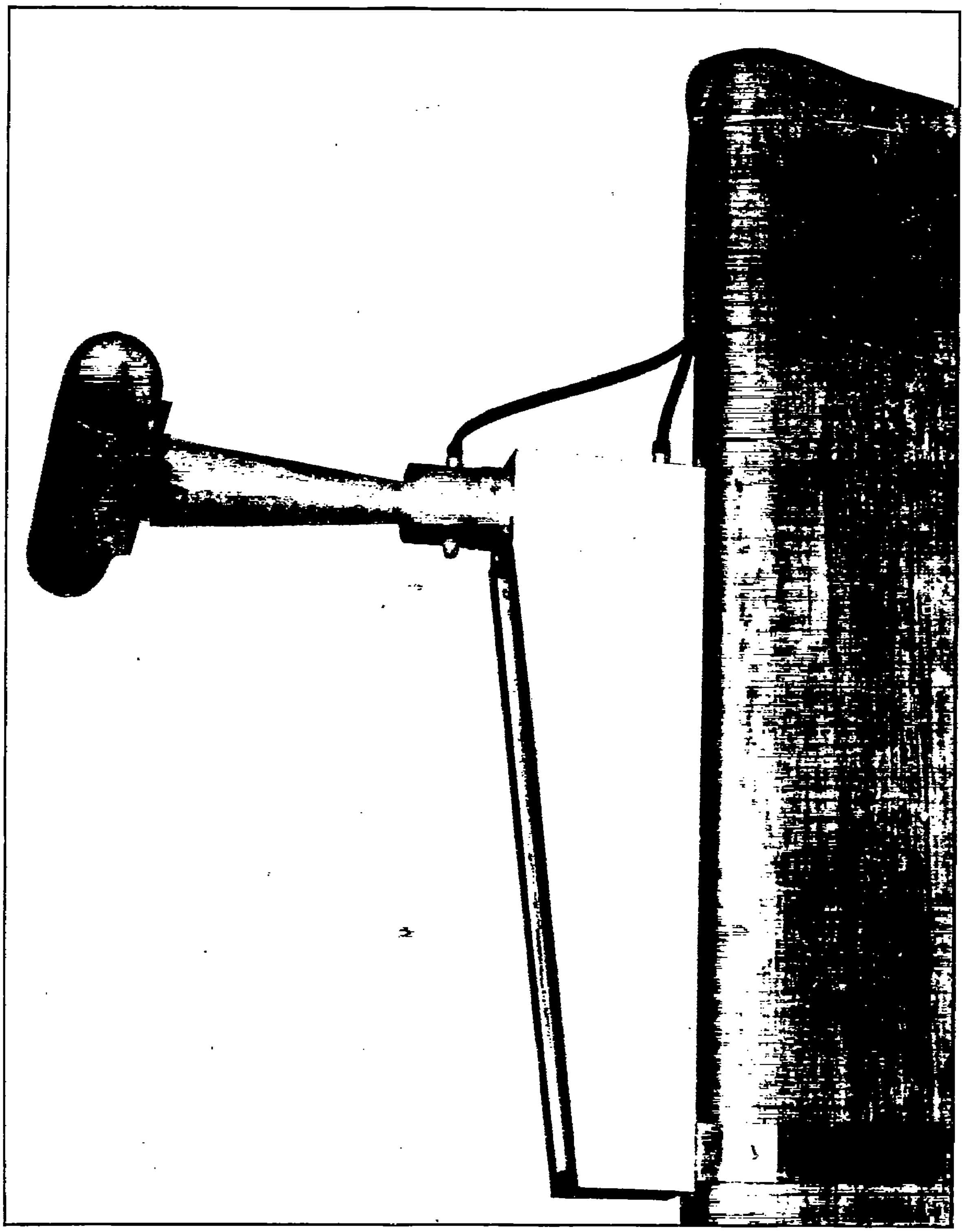


FIG. 18.—HOODED DOUBLE-THROAT PITOT-VENTURI.